CALIFORNIA DIVISION OF MINES AND GEOLOGY

FAULT EVALUATION REPORT FER-182
EASTERN NORTH FRONTAL FAULT ZONE, AND RELATED FAULTS, SOUTHWESTERN SAN BERNARDINO COUNTY

by

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INTRODUCTION

Potentially active faults in southwestern San Bernardino County that are evaluated in this Fault Evaluation Report (FER) include strands of the North Frontal fault zone (NFFZ), southern segments of the Helendale, Old Woman Springs, and Silver Reef, and related faults (figure 1). The northeastern San Bernardino Mountains study area is located in parts of the Bighorn Canyon, Rattlesnake Canyon, Big Bear City, Fawnskin, and Lucerne Valley 7 1/2-minute quadrangles (figure 1). The eastern NFFZ will be evaluated in this FER. The western NFFZ and related faults are evaluated in FER 186. Only the southernmost traces of the Helendale, Old Woman Springs, and Silver Reef faults are evaluated in this FER. Segments of these faults northwest of the study area have been evaluated by Manson (see FER's 176, 177). These faults are evaluated as part of a statewide effort to evaluate faults for recency of activity. Those faults determined to be sufficiently active and well-defined are zoned by the State Geologist as directed by the Alquist-Priolo Special Studies Zones Act (Hart, 1985).

SUMMARY OF AVAILABLE DATA

The northeastern San Bernardino Mountains study area is transitional between the Mojave Desert and Transverse Ranges geomorphic provinces. The Mojave Desert geomorphic province, located in the northern part of the study area, is characterized by generally northwest-trending, right-lateral strike-slip faults. In contrast, the Transverse Ranges geomorphic province, located in the southern part of the study area, is generally characterized by more east-trending structures. Both the northwest-trending and east-trending faults are the result of compressional tectonics along the San Andreas fault system. The interaction between these two tectonically active provinces has resulted in a structurally complex area.

Topography in the study area ranges from gently sloping alluvial fans to relatively steep, north-facing slopes. Development in the study area is generally low in the eastern part of the study area. Several quarries and cement plants are located in the western part of the study area, and the towns of Lucerne Valley and Apple Valley are located in the central and northwestern parts of the study area, respectively.

Rock types in the study area include pre-Mesozoic roof pendants comprised of gneiss, marble and quartzite, Mesozoic plutonic rocks, Tertiary Old Woman Sandstone, and Quaternary alluvium (Dibblee, 1964, 1967; Miller, 1975-77; Sadler, 1981; Meisling, 1984).

The most important late-Quaternary surficial deposits in the study area consist of a series of nested Pleistocene and Holocene alluvial fans. Meisling (1984) recognized three ages of alluvial fans in the western part of the study area.

NORTH FRONTAL FAULT ZONE

The North Frontal fault zone (NFFZ) is a major, range front fault zone along which uplift of the northern San Bernardino Mountains has occurred. The NFFZ consists of generally east-trending, south-dipping reverse and thrust faults that form a complex zone of discontinuous, multiple strands up to 5 km wide (Ziony, 1985). Locally, northwest-trending, high-angle faults also occur within the NFFZ.

Cumulative displacement along the NFFZ is not well-documented. The onset of deformation and uplift in the northern San Bernardino Mountains is thought to have commenced during middle-to-late Pliocene time and has continued through late Pleistocene time (Meisling, 1984; Dibblee, 1975, Sadler, 1981, 1982). Meisling reported that vertical displacements of Pleistocene alluvial fans (his Qf2 unit) probably do not exceed 40 meters in the western part of the study area. In the eastern part of the study area, scarps in Pleistocene alluvial fans are as high as 60 meters (Bull, 1978) (locality 17, figure 2b). Although ages of these alluvial fans are not precisely known, preliminary age estimates during this study suggest that alluvial fans equivalent to Meislings' Qf2 unit in the western part of this study are approximately 130,000 years old, based on soil-profile development, degree of surficial weathering of boulders, and degree of preservation of constructional surface-morphology (Borchardt, 1986; Appendix). Thus, very preliminary slip-rate estimates suggest late Quaternary slip-rates on the order of about 0.15 to 0.3 mm/yr. Clark and others (1984) reported a late Quaternary slip-rate of 0.07 to 0.14 mm/yr along the Ord Mountain fault zone, located west of the study area along a segment of the NFFZ. Meisling (1984) estimated that faults along the west flank of the Ord Mountains have a vertical slip-rate of less than 1 mm/yr.

Mendenhall (1905) first recognized that the San Bernardino Mountains is an extremely youthful mountain range, based on the extensive upland erosion surface and the steep north-facing escarpment. Vaughn (1922), Woodford and Harriss (1928), Gillou (1953), Richmond (1960), and Hollenbaugh (1968) all reported evidence of late Cenozoic deformation and faulting along the north front of the San Bernardino Mountains. These maps are not evaluated in this FER because either the scale of the maps is too small, or the mapping (especially of late Quaternary faulting) is too generalized. Mapping that is evaluated in this FER includes Dibblee (1964, 1967), Miller (1975-77), Sadler (1981), Rzonca and Clark (1982), and Meisling (1984). None of these maps are annotated with geomorphic evidence of recent faulting.

The NFFZ in the study area is comprised of many discontinuous fault segments, many of which are unnamed, or have more than one name. Thus, for purposes of discussion in this FER, the NFFZ will be divided into four areas, based on geographic location, trend, and complexity of faulting (figure 1).

Area A, located in part of the Bighorn Canyon and Rattlesnake Canyon quadrangles, is characterized by a west-northwest-trending, relatively simple fault zone east of the Old Woman Springs fault (figure 1). Area B, located in the Rattlesnake Canyon quadrangle, is characterized by east-west-trending, discontinuous, occasionally arcuate reverse faults. Area C, located in the Big Bear City quadrangle, is characterized by north to northwest-trending faults in the Blackhawk landslide area. Area D, located in parts of the Big Bear City, Fawnskin, and Lucerne Valley quadrangles, is a very complex, wide zone of reverse and subsidiary normal faults that generally trend east-west.

Dibblee (1964, 1967) mapped the entire NFFZ in the study area at a scale of 1:62,500 (figures 2a-2d). Dibblee depicts the NFFZ as a generally east-trending, south-dipping series of reverse faults. At the eastern end of Area A, Dibblee mapped the NFFZ as concealed by late Pleistocene alluvium (locality 1, figure 2a). However, late Pleistocene alluvial fans are offset at locality 2 (figure 2a). Holocene alluvium is juxtaposed against bedrock in Area B (locality 3, figure 2b), and farther west, late Pleistocene alluvial fans are offset. Holocene alluvium is mapped as offset along northwest-trending faults in Area C (localities 4 and 5, figure 2c). Area D is a complex, wide zone consisting of several fault strands that, in part, reflect the structural complexities produced by the intersection of the Helendale fault and NFFZ (figures 2c, 2d). Late Pleistocene alluvial fans are offset along east-west-trending thrust faults that form a zone up to 2 km wide in the Cushenbury area (figure 2c). In cross section, Dibblee depicted these faults as a series of south-dipping, imbricate thrust faults. Dibblee mapped late Pleistocene alluvium faulted against Holocene alluvium at localities 6 and 7 (figure 2d). Holocene alluvium is offset along a short, west-northwest-trending fault at locality 8 (figure 2d).

Miller (1975-77) mapped the entire NFFZ in the study area at a scale of 1:48,000 (figures 2a-2d). Although similar to the mapping of Dibblee (1964, 1967), Miller mapped the NFFZ in much more detail, depicting a broad, complex zone of thrust and reverse faults. However, Miller did not annotate his map with geomorphic evidence of recent faulting. Late Pleistocene alluvial fans are offset along segments of the NFFZ in Area A (locality 9, figure 2a), Area B (localities 10, 11, figure 2b), Area C (locality 12, figure 2c), and Area D (localities 13, 6, and 7, figures 2c and 2d). Holocene alluvium generally is not offset along the NFFZ except for north-facing scarps in alluvium at Cushenbury Springs (locality 14, figure 2c). Elsewhere, Holocene alluvium is juxtaposed against late Pleistocene alluvium (e.g., localities 10, 15, figures 2b, 2d).

Sadler (1981) mapped a very complex series of faults in the northern San Bernardino Mountains at a scale of 1:24,000. Late Quaternary faults were not distinguished from older faults in the study area. In a very generalized sense, Sadler's mapping of the NFFZ doesn't differ greatly from Dibblee (1964, 1967) or Miller (1975-77). Thus, only those faults of Sadler that differ significantly from Dibblee (1964, 1967) or Miller (1975-77) were plotted on figures 2a-2d. Faults mapped by Sadler do not offset active alluvial fan surfaces (Holocene) in the study area, although relict fan surfaces (late Pleistocene to early (?) Holocene) are offset (e.g., localities 9, 16, figures 2a, 2b).

Bull (1978), in a reconnaissance assessment of faults in the Mojave Desert area, classified the NFFZ as a Class I (active) fault zone. Bull reported that offset late Pleistocene alluvial fans are common along the range front. Evidence of multiple displacements was reported by Bull at locality 17 (figure 2b). The main fault scarp here is approximately 60 meters high.

Terraces within the stream canyon and benches parallel to the scarp suggest as many as five episodes of uplift (Bull, 1978, p. 137).

Rzonca and Clark (1982) mapped a small area along the NFFZ at Kaiser Cement Corporation's Cushenbury facility (figure 4). They mapped two south-dipping segments of the NFFZ and reported that both of these fault segments offset Holocene alluvium. They reported that displacement along the northern fault segment probably occurred no more than a few hundred years ago, based on their interpretation of rates of erosion in the Cushenbury area. This interpretation of the age of alluvial fans in the Cushenbury area is in contrast to Sadler's contention that it is difficult to distinguish late Pliocene fanglomerates from late Pleistocene deposits (1983 p.c. to Meisling-reported in Meisling, 1984).

Meisling (1984) mapped a complex zone of south-dipping thrust faults in the western part of the study area (figure 2d). Meisling called this zone of faults the White Mountain Thrust system and stated that most segments of the fault zone have not moved since middle Pleistocene time. Segments of the White Mountain Thrust system that offset late Pleistocene alluvial fans (locality 7, figure 2d) are thought by Meisling to be reactivated, low-angle thrust faults and, possibly, large-scale landsliding. Only those segments of the White Mountain Thrust system that offset late Pleistocene deposits are shown on figure 2d.

HELENDALE FAULT

The Helendale fault north of the study area is a major right-lateral strike-slip fault with a late Quaternary slip-rate estimated to be 0.15 to 0.7 mm/yr by Bird and Rosenstock (1984) and 1 mm/yr by Clark and others (1984). The Helendale fault north of the study area was evaluated for recency of faulting by Manson (FER-176, 1986), and most of the fault was recommended for zoning for special studies.

The Helendale fault zone in the study area is a 20-km-long, northwest-trending fault zone delineated by a main trace and a north branch fault (figures 2b, 2c). Sense and magnitude of displacement along the Helendale fault zone south of its intersection with the NFFZ are not well-documented. Dibblee (1967) indicated that down-to-the-east vertical displacement has occurred along the main trace and down-to-the-west vertical displacement occurred along the north branch fault. Sadler (1981) reported that right-lateral strike-slip displacement is minimal along the Helendale fault in the northern San Bernardino Mountains. Sadler reported that the Helendale fault extends southward into the mountains as a southward tapering graben with only minor strike-slip displacement.

Dibblee (1964, 1967) mapped a continuous, northwest-trending fault zone that apparently is not offset at the intersection with the NFFZ (figure 2c). The fault is concealed by Holocene alluvium at the mouth of Cushenberry Canyon, where pre-Mesozoic bedrock is offset. Late Pleistocene and Holocene alluvium are juxtaposed against bedrock southeast of Cactus Flat along the main trace (localities 18 and 19, figure 2c), and the north branch fault (locality 20, figure 2b).

Hollenbaugh (1968) mapped segments of the Helendale fault in the Cushenbury area, although he apparently mis-mapped the fault north of the study area in the Cougar Buttes quadrangle (faults mapped by Hollenbaugh not plotted on figures 2b, 2c). Hollenbaugh reported that the Helendale fault offsets the NFFZ, but he shows an apparent left-lateral separation of about 150 meters. This discrepancy is explained by right-lateral, oblique-slip with a significant component of down-to-the-east displacement of a south-dipping fault plane. This explanation doesn't seem plausible.

Sadler (1981) mapped segments of the Helendale fault zone south of the NFFZ primarily as a west-dipping reverse fault in bedrock (figures 2b, 2c). Short, discontinuous fault segments juxtapose bedrock against late Pleistocene and Holocene alluvium (locality 19, figure 2c; locality 23, figure 2b). Sadler did not map most of the north branch fault, except near locality 21 (figure 2c), where he indicated a component of right-lateral strike-slip displacement, and near locality 22 (figure 2b).

Morton and others (1980) mapped recently active segments of the Helendale fault zone, based on air photo reconnaissance mapping. Their emphasis was primarily north of the study area, and only very short segments of the fault zone just north of the NFFZ were mapped near Highway 18 (figure 2c).

OLD WOMAN SPRINGS FAULT

The Old Woman Springs fault is a right-lateral strike-slip fault that is typical of the northwest-trending faults in the Mojave Desert. The Old Woman Springs fault is part of the southern segment of the Lenwood fault zone. Late-Quaternary slip rates along the Lenwood fault zone are not well-constrained and range from 0.07 to 0.7 mm/yr (Bird and Rosenstock, 1984). The southern end of the Old Woman Springs fault is located in the study area. Most of this segment was evaluated by Manson (FER-177, 1986), and was recommended for zoning for special studies. Mapping shown on figure 2b includes Dibblee (1967), Miller (1975-77), Morton and others (1980), and Sadler (1981). Late Pleistocene alluvium is juxtaposed against Holocene alluvium along traces of the Old Woman Springs fault (figure 2b). Dibblee (1967), Morton and others (1980), and Sadler (1981) mapped northwest-trending branch faults west of the principal trace of the Old Woman Springs fault that offset late(?) Pleistocene alluvium (figure 2b).

SILVER REEF FAULT

The Silver Reef fault is a minor, northwest-trending, presumably right-lateral strike-slip fault (figure 2b). Dibblee (1967) mapped segments of the fault in the study area, showing late Pleistocene and, possibly, Holocene alluvium to be offset (locality 24, figure 2b). The Silver Reef fault just north of the study area is mapped by Dibblee as concealed by the 17,400 ybp Blackhawk landslide (Stout, 1977). Miller (1975-77) mapped a very short segment of the Silver Reef fault, as did Sadler (1981) (locality 25, figure 2b). Manson (1986b) evaluated the Silver Reef fault in FER-177. Although the fault does not offset Blackhawk landslide deposits in the FER-177 study area, it is probable that this short fault simply dies out prior to reaching the landslide.

INTERPRETATION OF AERIAL PHOTOGRAPHS AND FIELD OBSERVATIONS

Aerial photographic interpretation by this writer of faults in the northeastern San Bernardino Mountains study area was accomplished using U.S. Department of Agriculture (AXL, 1952-53, scale 1:20,000), U.S. Bureau of Land Management (CAHD-77, 1978, scale 1:30,000; CA93-77, 1977, scale 1:30,000), and U.S. Geological Survey (1945, scale 1:24,000; 1975, scale 1:13,000) air photos.

Approximately five days were spent in the study area in January and June 1986 by this writer. E. Hart and M. Manson accompanied this writer in January, and G. Borchardt provided soil descriptions for selected sites in June 1986. Results of these soil development surveys are presented in the Appendix and on figures 3a-3c. Selected fault segments were verified and subtle features not observable on the aerial photographs were mapped in the field. Results of aerial photographic interpretation and field observations by this writer are summarized on figures 3a-3c.

NORTH FRONTAL FAULT ZONE

The NFFZ in the study area generally is well-defined and is characterized by an extremely complex, broad zone of discontinuous fault segments (figures 3a-3c). Mapping by this writer, in a general way, verified faults mapped by Miller (1975-77) and Meisling (1984), although significant differences in detail exist (figures 2a-2d; 3a-3c). Faults mapped by Dibblee (1964, 1967), although somewhat generalized, were locally verified by this writer.

The NFFZ throughout most of the study area is delineated by moderately to well-defined, north-facing scarps in late Pleistocene alluvial fans. In Area D, just west of Cushenbury Springs, south-facing (mountain-side-down) scarps and grabens were mapped, indicating a considerable amount of complex deformation that is related to the interaction between the active Helendale fault and the NFFZ. No geomorphic evidence was observed to suggest that the Helendale fault right-laterally offsets segments of the NFFZ.

Evidence of Holocene displacement along much of the NFFZ is weak, although offset of late Pleistocene-age alluvial fans is common. In Area A, permissive evidence of Holocene displacement was observed at locality 26 (figure 3a). Here, a north-facing scarp in Holocene alluvium is probably related to the interaction between the Old Woman Springs fault and the NFFZ (figure 3a; appendix-Borchardt, 1986). However, this fault was not mapped by Sadler (1981), Miller (1975-77), or Dibblee (1967), and there is some doubt as to the origin of the feature. Just to the west, alluvium, thought to be about 2,000 years old, is not offset (OHS-2, Borchardt, 1986).

Permissive evidence of latest Pleistocene to Holocene displacement in Area C was mapped by Miller (1975-77) and verified by this writer at locality 12 (figures 2c, 3b). Landslide deposits assumed to be equivalent to the Blackhawk landslide (age 17,400 yrs., Stout, 1977) are offset along a northwest-trending fault, and a tonal lineament in Holocene alluvium is associated with the east-facing scarp (figure 3b). Additional geomorphic evidence of recent faulting may be related to landsliding in this area.

North-facing scarps in alluvium mapped as Holocene by Miller (1975-77) were verified by this writer, based on air photo interpretation, and indicate

Holocene activity at Cushenbury Springs in Area D (locality 14, figures 2c, 3b). Evidence of multiple offsets was observed at locality 27 (figure 3b). At this location, a well-defined, north-facing scarp in a late Pleistocene alluvial fan (approximately 20,000 ybp, Borchardt, 1986) is characterized by a composite scarp slope (figure 3b). Two terraces within a drainage incised across the scarp are also offset, indicating Holocene faulting. The Stage III K horizon developed in the 20,000-year-old alluvial fan is clearly truncated near the base of the north-facing scarp about 100 meters west of locality 27 (figure 3b; photo 1). A roadcut exposure of this fault was observed at locality 28 (figure 3c; photo 2). The attitude of the fault at this location is N60^{o}E 40^{o}SE. Late Pleistocene alluvium is thrust over alluvium and a B horizon. A well-defined fault plane with slickensides was not observed.

Although segments of the NFFZ are generally well-defined west of the Cushenbury area, evidence of Holocene displacement is limited to tonal lineaments and vegetation contrasts in Holocene alluvium (figure 3c). A terrace surface tentatively thought to be about 40,000 years old (GP1; Borchardt, 1986) is vertically offset along a strand of the NFFZ at locality 29 (figure 3c). A lower, younger terrace (approximately 2,000 years old - GP-2; Borchardt, 1986) is not offset (figure 3c).

The northern fault mapped by Rzonca and Clark (1982) was mostly verified by this writer, based on air photo interpretation (locality 30, figure 3b). A north-facing scarp and tonal lineament in latest Pleistocene and Holocene alluvium indicates Holocene activity. However, it is unlikely that the alluvial fans offset along this fault are as young as reported by Rzonca and Clark (1982).

HELENDALE FAULT

The Helendale fault in the study area does not have geomorphic evidence of systematic right-lateral strike-slip displacement south of the NFFZ (figures 3a, 3b). There is no compelling geomorphic evidence to suggest that the active, right-lateral strike-slip Helendale fault north of the study area is continuous southeast of and offsets the NFFZ. It appears that the very complex intersection between the two fault zones is expressed by the broad zone of discontinuous reverse and normal faulting in and just west of the Cushenbury area (figures 2c, 2d, 3b, 3c).

The faults mapped by Dibblee (1964) in Cushenbury Canyon were not verified as Holocene active faults (figures 2c, 3b). Two short, north-northwest to northwest-trending fault segments just east of Cushenbury Canyon mapped by this writer and partly mapped by Sadler (1981) are suggestive of strike-slip displacement (right-laterally deflected drainages, linear trough) (locality 31, figure 3b). Southeast of this location, the Helendale fault is delineated by a moderately well-defined, east-facing escarpment in bedrock (figures 3a, 3b). Geomorphic evidence of Holocene right-lateral strike-slip or vertical displacement was not observed although geomorphic evidence permissive of Holocene displacement exists locally (localities 32 and 33, figure 3b). Faults in bedrock observed at localities 32 and 34 (figure 3b) indicate that segments of the Helendale fault zone are west-dipping reverse and thrust faults with a component of right-lateral strike-slip displacement.

The north branch of the Helendale fault mapped by Dibblee (1964, 1967) and partly mapped by Sadler (1981) is delineated by a moderately well-defined, arcuate, west-to-southwest-facing bedrock escarpment (figures 3a, 3b).

Associated geomorphic features indicating Holocene reverse or strike-slip displacement were not observed.

OLD WOMAN SPRINGS FAULT

The principal trace of the Old Woman Springs fault in the study area is generally well-defined and is delineated by geomorphic features indicating right-lateral strike-slip displacement, such as right-laterally deflected drainages, scarps in Holocene alluvium, and associated tonal lineaments (figure 3a). Branch faults located west of the Old Woman Springs fault mapped by Dibblee (1967) and Sadler (1981) were only partly verified, but are moderately to poorly defined, and are not characterized by geomorphic features indicating Holocene displacement (figures 2b, 3a).

SILVER REEF FAULT

The Silver Reef fault is a moderately well-defined, northwest-trending strike-slip fault (figure 3a). The fault mapped by Dibblee (1967) was generally verified by this writer, based on air photo interpretation. The fault offsets late Pleistocene alluvial fans and associated tonal lineaments in young alluvium suggest Holocene displacement (localities 35 and 36, figure 3a). Both left-laterally and right-laterally deflected drainages were observed along the fault (figure 3a). The lack of systemmatically deflected drainages probably indicates a very low slip-rate for this fault.

SEISMICITY

Seismicity in the northeastern San Bernardino Mountains study area is depicted in figure 5. A and B quality epicenter locations by California Institute of Technology are for the period 1932 to 1985.

The North Frontal fault zone in the study area is seismically active. Clusters of epicenters occur south of the range front, consistent with displacement at depth along a south-dipping thrust fault zone. However, it is difficult to relate specific seismic events with specific faults due to the complexity of the fault zone. A cluster of epicenters occurs near the intersection of the NFFZ and Helendale fault zone (figure 5). Hamilton and Hadley (1976) studied focal mechanisms for a group of six earthquakes near the intersection of the NFFZ and Helendale fault. The relocated events show an east-northeast trend and the focal mechanisms indicate a south-dipping structure with left-lateral, thrusting movement.

The Helendale fault zone southeast of the NFFZ is characterized by epicenters in proximity to the fault (figure 5). Although the Helendale fault in the study area may be active at depth, it is not delineated by a well-defined zone of seismicity.

The Old Woman Springs fault is associated with seismicity, but it is not delineated by a well-defined zone of microseismicity (figure 5). The Silver Reef fault apparently is not characterized by seismicity.

CONCLUSIONS

NORTH FRONTAL FAULT ZONE

The NFFZ is a major, east-west-trending fault zone that marks the boundary between the Transverse Ranges and Mojave Desert geomorphic provinces. The NFFZ is characterized by a broad, complex zone of discontinuous, south-dipping reverse and thrust faults. Locally, northwest-trending, high-angle faults occur within the NFFZ. Faults within the NFFZ generally are well-defined and are delineated by geomorphic features indicating Holocene reverse faulting (e.g., localities 12, 14, 26, 27, 29, 30, figures 3a-3c). However, well-defined scarps are generally found in late Pleistocene alluvial fans (approximately 20,000 ybp to 130,000 ybp)--Holocene alluvial fans are not offset except at localities 14, 26, and 27 (figures 3a and 3b). Both Sadler (1981) and Meisling (1984) have stated that thrust faulting along the NFFZ did not continue into the Holocene. Evidence of Holocene displacement is not strong along the NFFZ. Nonetheless, faults in late Pleistocene alluvium are generally well-defined, the NFFZ is a major range front fault, geomorphic evidence indicating Holocene displacement was observed during this study, and the fault zone is seismically active at depth.

HELENDALE FAULT

The Helendale fault in the study area is a northwest-trending fault zone delineated by a moderately well-defined bedrock escarpment. Faults mapped by Dibblee (1964, 1967) were generally verified except in Cushenbury Canyon. Geomorphic evidence of Holocene right-lateral strike-slip displacement was not observed by this writer, based on air photo interpretation. Exposures of fault planes in bedrock indicate that the Helendale fault southeast of its intersection with the NFFZ is probably a west to southwest-dipping, reverse-oblique slip with a component of right-slip (locality 34, figure 3b). Geomorphic evidence of Holocene reverse-oblique slip faulting generally was not observed by this writer along the Helendale fault or the north branch of the Helendale fault (figures 3a-3b). Geomorphic evidence of possible minor Holocene displacement was observed at locality 33 (figure 3b). It is conceivable that the Helendale fault, once a continuous fault prior to the uplift of the San Bernardino Mountains during late Pliocene and Pleistocene time along the NFFZ, has since been isolated south of the NFFZ and only occasionally is reactivated in response to compressional stress within the San Bernardino Mountains.

OLD WOMAN SPRINGS FAULT

The Old Woman Springs fault is right-lateral strike-slip fault with geomorphic evidence of Holocene faulting in the study area (figure 3a). Manson (FER-177, 1986) evaluated the Old Woman Springs fault and recommended zoning for special studies. Branch faults west of the Old Woman Springs fault, mapped by Dibblee (1967) and Sadler (1981), generally are not well-defined and are not delineated by geomorphic evidence of Holocene faulting (figures 2b, 3a).

SILVER REEF FAULT

The Silver Reef fault is a northwest-trending, presumably right-lateral strike-slip fault. The fault mapped by Dibblee (1967) was generally verified by this writer as a moderately well-defined fault delineated by tonal lineaments in Holocene alluvium which are permissive of Holocene faulting (localities 35, 36, figure 3a). The Silver Reef fault north of the study area does not offset Blackhawk landslide deposits. However, it is probable that the fault dies out prior to reaching the landslide.

RECOMMENDATIONS

Recommendations for zoning faults for special studies are based on the criteria of "sufficiently active" and "well-defined" (Hart, 1985).

NORTH FRONTAL FAULT ZONE

Zone for special studies well-defined faults shown on figures 6a-6c. Principal references cited should be Miller (1975-77), Meisling (1984), and this FER.

HELENDALE FAULT

Do not zone for special studies. This fault is neither sufficiently active nor well-defined in detail.

OLD WOMAN SPRINGS FAULT

Zone for special studies well-defined faults shown on figure 6a. Principal references cited should be Miller (1975-77), Manson (1986b), and this FER.

SILVER REEF FAULT

Zone for special studies well-defined faults shown on figure 6a. Principal references cited should be Dibblee (1967) and this FER.

Report reviewed and airphotos checked. I agree with recommendations. Earl W. Hart 10/17/86

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The following soil descriptions are taken from "Preliminary analysis of offset soils along faults in the west-central Mojave Desert, California" by Glenn Borchardt, June 1986. The locations of specific soil description sites are shown on figures 3a, 3b, and 3c of FER-182.

INTRODUCTION

This report contains descriptions and preliminary age estimates of offset soils along fault zones in the west-central Mojave Desert. Except for the Blackhawk landslide dated at 17,400 B.P. (Stout, 1977), there are no absolute dates on alluvial materials or soils in the area. The youngest major alluvial event in southern California occurred about 10,000 years ago (Borchardt and Hill, 1985) as a result of the change from a wet, cool climate to a dry, hot climate at the end of the Pleistocene (Bull, 1978). The great extent of this alluvial event is well documented in the exposures in a 275-km trench across the Mojave from Victorville to the Colorado River (Sharp, 1984) and generally makes the distinction between Holocene and Pleistocene soils relatively easy.

Unfortunately, the only soil survey in the area covers the Mojave river area near Barstow to the north (Storrie and Trussell, 1937). Probably the most applicable relative soil ages are those mentioned by Bull (1978) and those obtained for Antelope Valley in a similar climate to the north (Ponti, 1985). Less applicable are those from the San Gabriel Mountains in a wetter regime to the south (Tinsley, Matti, and McFadden, 1982).

The difficulty of soil age dating in the west-central Mojave is compounded by the fact that the calcareous alluvium in the area appears to weather in ways entirely different from the dominant granitic alluvium. Bt horizons, for example, apparently do not begin to form in calcareous materials until the original carbonate has been entirely leached from the surface. With current mean annual rainfall in the area being on the order of 9-20 cm, this leaves the maximum depth of leaching in Holocene soils at equivalent depths of 9-20 cm. Even with three times this amount of rainfall during the Pleistocene (McFadden, 1982), Bt horizons apparently do not form in the calcareous materials of the region for at least 100,000 years.

The text includes a discussion of each of the soils in the order in which they were described and sampled.

CLIMATE

Barstow has a mean annual temperature of $18^{o}C$ (64^{o}) and mean annual precipitation of 9.2 cm (3.62 in.) at an elevation of 632 m (2,105 feet) (Storrie and Trussell, 1937). The field area is to the south and ranges up to an elevation of 1800 m (6,000 feet) where the precipitation is considerably greater.

BH-1

Big Horn Road

Estimated Age: 130,000 B.P.

Range: 80,000-130,000 B.P.

This relict soil is on a fan remnant in a ravine up Big Horn Road south of Highway 247 between Yucca Valley and Lucerne Valley. The A horizon is 27 cm thick and may actually consist of a veneer of younger materials. The Bt horizon extends from 27 to 108 cm. The bottom of the Bt has a distinctive beta-B horizon 1-cm thick (Photo 061086-36) in which the clay films are especially thick and the demarcation with the underlying parent material exists within a mm or two.

BH-2

Big Horn Road

Estimated Age: 130,000 B.P.

Range: 80,000-130,000 B.P.

A shallow ($\leq$ 15 cm) excavation along the entire scarp face uncovered the top of a Bt horizon similar to the one at BH-1. This indicates that the scarp probably has had less than 80 cm of movement in the last 130,000 years. A trench across the scarp would test this hypothesis.

BH-3

Big Horn Road

Estimated Age: 130,000 B.P.

Range: 80,000-130,000 B.P.

This site exists where a major drainage has exposed a cross section perpendicularly across a 5-m-high scarp along the Frontal Fault Zone of the San Bernardino Mountains. The headwall contains a soil similar to the one at BH-1. The scarp face has a slope of 26 degrees and appears to be underlain by a series of 3-5 paleosols on the footwall. Each paleosol seems to represent soil formation that is a fraction of that at BH-1. Carbonate deposition exists at the base of the lower paleosol and in the relict soil on the headwall (Photos 061086-05 through 08). Sample 86B036 was a piece of wood from a log found on a treeless alluvial fan to the west. The exterior of the log has the swirled appearance characteristic of bristle cone pine. The nearest trees are on the slopes at least a mile to the south.

RH-1

Rock House

Estimated Age: 130,000 B.P.

Range: 80,000-130,000 B.P.

This site is cut in a drainage about 2.5 km west of Rattlesnake Spring near an abandoned homestead built mostly with rocks. It lies about 200 m downslope from a 20-m-high scarp to the south. The A horizon is 12 cm thick and is overlain by a moderately well developed desert pavement. The Bt horizon is 55 cm thick, being developed in granodiorite that is completely saprolitic and contains clay films throughout. The Cr horizon is gray saprolite lacking clay films. The K horizons in the cobble below extend to at least 6 m. This is not particularly unusual, because coarse materials typically hold little moisture and thus allow carbonate to precipitate at great depths (McFadden and Tinsley, 1985). Elsewhere in the cutbank, evidence exists for at least two other K horizons at 3- and 4-meter depths.

CP -1

Clay Pit at Kaiser Cement

Estimated Age: 20,000 B.P.

Range: 15,000-30,000 B.P.

Developed in dolomitic and calcitic limestone alluvium, the soils above and below the scarps at this locality exhibit features similar to those at the Blackhawk Slide (BS-1). A ravine across one scarp revealed a K horizon similar to the one at Blackhawk. No B Horizons or their remnants were visible in the area although the K horizons had stage III development in cobble for depths over 1 m. The cobbly, sandy loam soils were 10YR5/3d, 3/4 m and had carbonate undercoats 2-5 mm thick within the upper 20 cm. Desert pavement was moderately well developed and the upper surface of limestone cobbles were etched, while the lower surfaces were not.

CP-2

Clay Pit at Kaiser Cement

Estimated Age; 230,000 B.P.

Range: 130,000-330,000 B.P.

This soil has a Bt horizon up to 100-cm thick. Although the colors were only 7.5YR4/4d, we estimate that such Bt horizon development must take considerably longer on calcareous alluvium than on granitic alluvium in which similar colors are found in 130,000 B.P. soils. The K horizon is stage III in cobble and extends for the full depth of the roadcut--over 5 m. As explained below, this may be a result of multiple K horizons.

KRC-1

Kaiser Railroad Cut

Estimated Age: 9,000 B.P.

Range: 8,000-13,000 B.P.

At first appearance, this 6-m section gives the impression that Holocene soil development in cobbly limestone alluvium is capable of producing extraordinarily thick K horizons in spite of the meager precipitation in the area. Actually, only the surface veneer is Holocene--the rest of the section has at least two relatively indistinct paleosols. The modern soil has only a thin $<$ 1 mm carbonate coating beneath the cobbles in the 20-60 cm interval that comprises the KI horizon. No coatings exist in the C horizon. The paleosols beneath the surface soil are difficult to observe because soil development in this material consists mostly of the dissolution of limestone and its reprecipitation at lower depths. Each paleosol tends to contribute caliche to the ones below it. The first paleosol exists at about the 100-cm depth and another, which we sampled, exists at the 300-cm depth. Its IIIAb horizon is 15 cm thick and its IIIKIb is 35 cm thick. The IIIKIb horizon has clasts whose undersides are coated with $>$ 3 mm of carbonate, indicating that it has undergone at least 3 times the development found in the surface soil.

OHS-1

One Hole Spring

Estimated Age: 9,000 B.P.

Range: 8,000-13,000 B.P.

The soil was excavated into the hanging wall of a moderate scarp in granitic alluvium about 2 km northeast of One Hole Spring on the Rattlesnake Canyon quad. The K horizon was uncovered at about the 15-cm depth where cobble had undercoats $<$ 0.5 thick.

OHS-2

One Hole Spring

Estimated Age: 2,000 B.P.

Range: 500-5,000 B.P.

The soil was excavated into the hanging wall of a small scarp in granitic alluvium to the west of OHS-1. No K horizon was found in an excavation to over 30 cm. Baring its production as an erosion scarp, this is evidence that this portion of the Frontal Fault is active.

OHS-3

One Hole Spring

Estimated Age: 20,000 B.P.

Range: 15,000-40,000 B.P.

The soil was excavated into the hanging wall of a small scarp in granitic alluvium to the east of OHS-1. The K horizon was found at the 20-cm depth. The undercoats were $>$ 0.5 mm thick and effervesced violently with dilute HCl.

GP-1

Gas Pipe

Estimated Age: 40,000 B.P.

Range: 20,000-80,000 B.P.

The soil was excavated into the hanging wall of a small scarp in a stream terrace. Although the soil consisted almost entirely of large boulders, it was penetrable to a depth of 35 cm where a saprolitic Bt horizon was encountered. The A horizon was sandy loam (10YR5/3d, 4/3m) and the Bt was coarse, sandy clay loam (10YR5/4d, 4/4m) which had subangular blocky structure with thin, patchy clay films on sand grains.

GP-2

Gas Pipe

Estimated Age: 2,000 B.P.

Range: 500-11,000 B.P.

This soil was excavated into a small unfaulted stream terrace in granitics about 5 m north of GP-1. The upper 13 cm consists of a coarse, sandy A horizon with 10YR6/3d color. A medium sandy IIA horizon exists from 13 to 25 cm and has a 10YR5/4d color. The IIC horizon (10YR5/4d) extends to 62 cm where unweathered granitics were encountered. The following pH data were obtained:

Depth, cm	pH
0	6.53
10	6.52
20	6.50
30	6.34
40	6.10
50	6.26
60	5.74
70	6.15

The A horizon has pH's above 6.5 and the C horizon has pH's below 6.5, which probably indicates the recycling of plant material or the accumulation of traces of windblown carbonate. A reddish root from 60 cm had a pH of 5.16.

Roots may be responsible for the low pH's at depth. In any case, there was no indication of caliche precipitation at this site.

GP-3

Gas Pipe

Estimated Age: 2,000 B.P.

Range: 500-11,000 B.P.

This soil was excavated into a small inset stream terrace below the projection of the fault in the drainage immediately northeast of GP-2. The upper 75 cm consists of a dark cumulic coarse, loamy sand A horizon (10YR5/4d, 3/4m).

GP-4

Gas Pipe

Estimated Age: 4,000 B.P.

Range: 2,000-11,000 B.P.

This soil was excavated next to large Juniper in a small inset stream terrace about 100 m south of GP-3. The upper 25 cm is a sandy A horizon and the material beneath is a C horizon. This soil appears to be older than GP.3.

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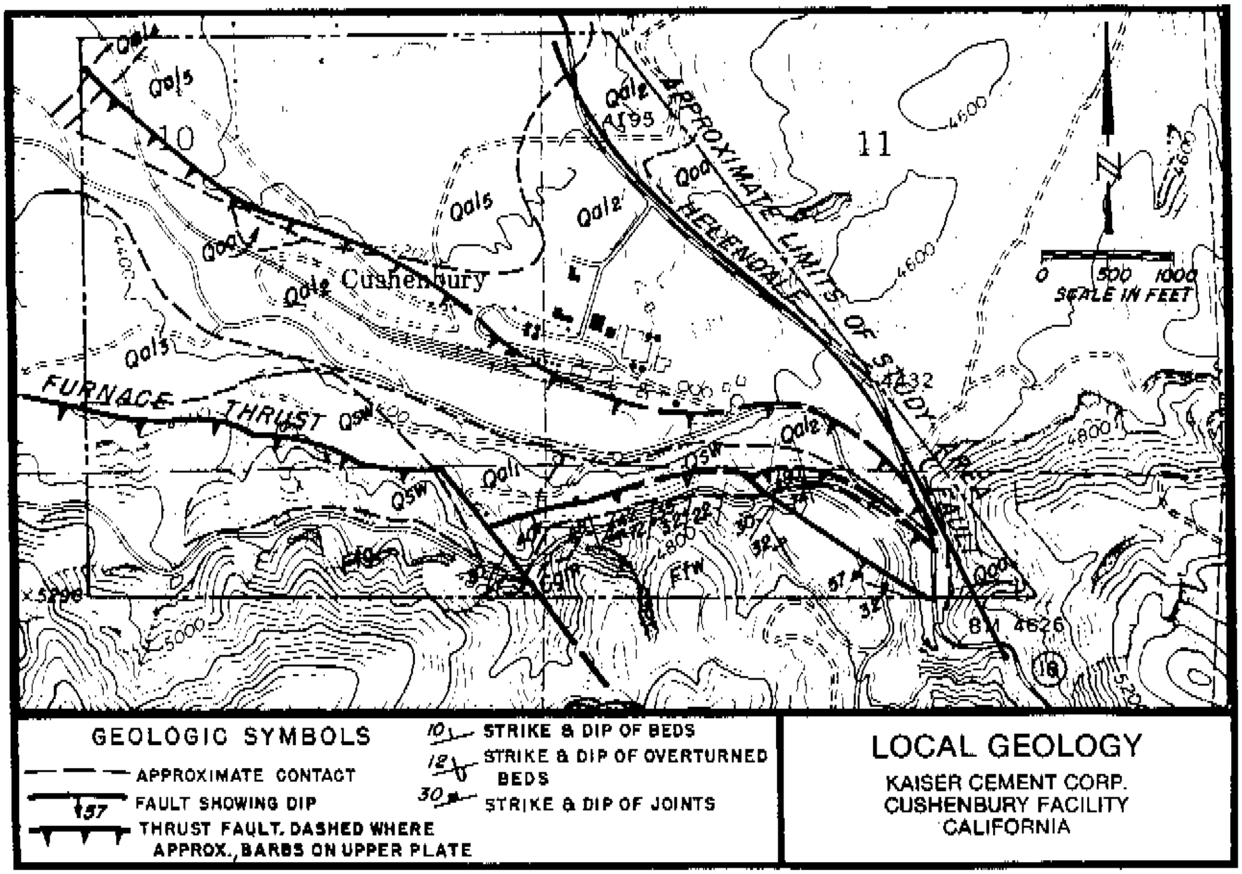

GEOLOGIC EXPLANATION

SURFICIAL DEPOSITS

Af Artificial Fill; undifferentiated

UNCONFORMITY

Qsw Slope Wash; fine to coarse sand, gravel and boulders; locally derived, uncemented

UNCONFORMITY

Qal 1 Qal 2 Qal 3 Qal 4 Qal 5

Younger Alluvial Deposits; fine to coarse sand, gravel and boulders; poorly bedded; locally derived; probably coeval; differentiated on the basis of source and lithology

- Qal 1 Marble Canyon alluvial fan; predominantly carbonate gravel and boulders
- Qal 2 Cushenbury Canyon alluvial fan, igneous and carbonate gravel and boulders
- Qal 3 Artic Canyon alluvial fan; igneous and carbonate gravel and boulders
- Qal 4 Artic Canyon stream deposit; predominantly igneous gravel and boulders
- Qal 5 Alluvium, finer grained sediments with a lower percentage of gravel and boulders

Qoa Older Alluvium; fine to coarse sand, gravel and boulders; weakly cemented; weathered

BEDROCK

FAULT

Kqm Cactus Quartz Monzonite; medium grained; subhedral texture

FAULT

Ffw Ffg

FURNACE FORMATION; fine to coarse grained marbles; laminated; fractured; white (Ffw) and gray (Ffg) colored

RECENT | HOLOCENE | CENOZOIC | CRETACEOUS | MESOZOIC | CARBONIFEROUS | PALEOZOIC

Figure 4 (to FER-182). Geologic map of the Kaiser Cement Corporation, Cushenbury facility, from Rzonka and Clark (1982).

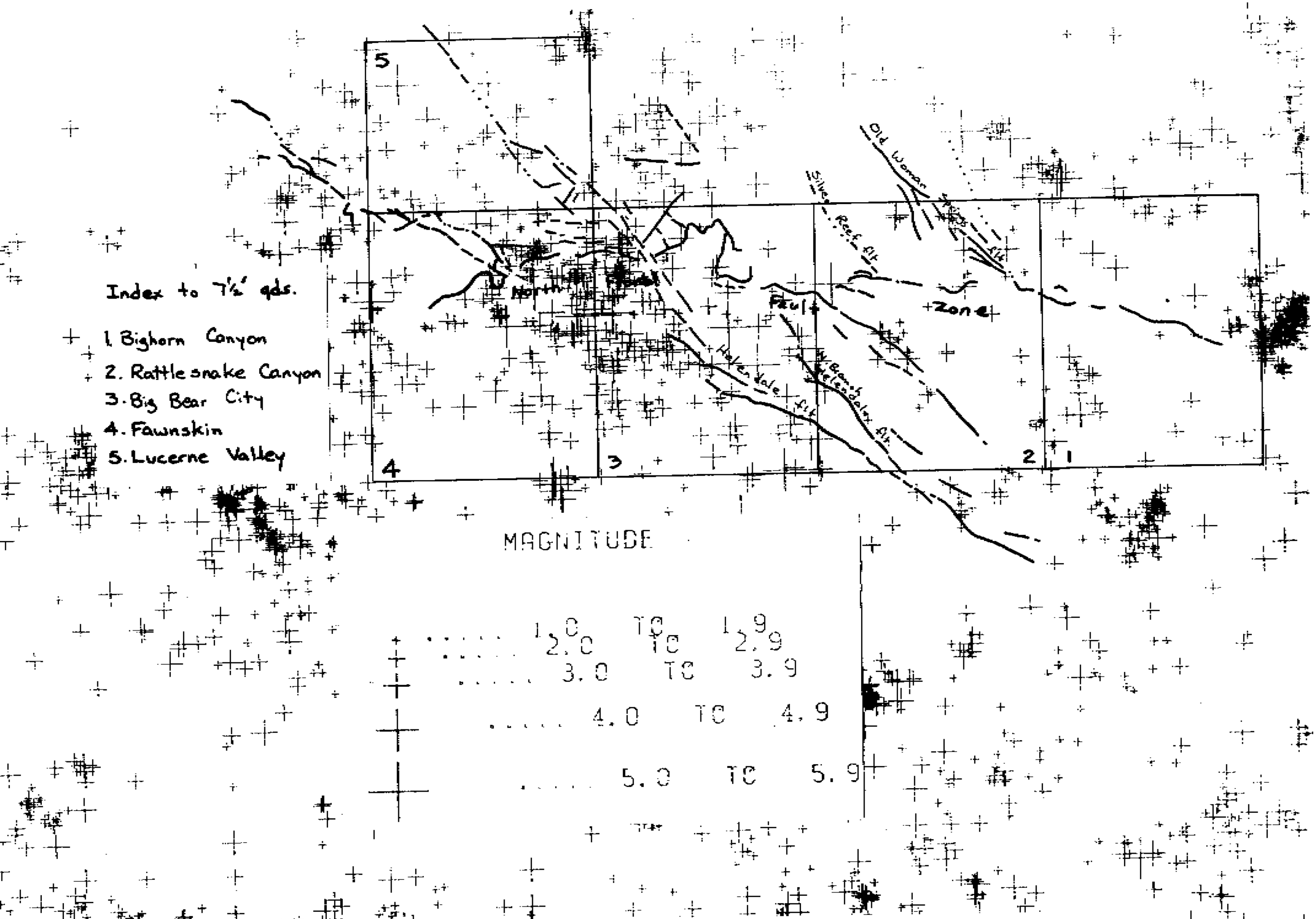

Figure 5 (to FER-182). Seismicity (A and B quality) in the northeastern San Bernardino Mountains study area for the period 1932 to mid-1985, based on locations from California Institute of Technology (1985). Faults are from Rogers (1967) and Bortugno and Spittler (1986).

Photo 1 (to FER-182). View west along a segment of the North Frontal fault zone near locality 27 (figure 3b). The stage III K horizon (>1 meter thick) developed on the alluvial fan (~20,000ybp, Borchardt, 1986) is truncated at least 2 meters by down-to-the-north reverse faulting. Although fault plane is not exposed, the fault is assumed to be located at the base of the north-facing scarp near Joshua Tree in center foreground.

Photo 2 (to FER-182). View northeast of roadcut exposure of thrust fault in alluvial fan at locality 28 (figure 3c). Fault (N60°E 40°SE) offsets B soil horizon developed on alluvial fan deposits. Minor drag folding in upper plate indicates reverse sense of displacement. A well-developed fault plane was not observed.